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CO_2-Emission Trading and Green Markets for Renewable Electricity

WILMAR - Deliverable 4.1

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Abstract (max. 2000 char.):

This report is Deliverable 4.1 of the EU project "Wind Power Integration in Liberalised Electricity Markets" (WILMAR) and describes the application of two policy instruments, Tradable Emissions Permits (TEP's) and Tradable Green Certificates (TGC's) for electricity produced from renewable energy sources in the European Union and the implications for implementation in the Wilmar model.

The introduction of a common emission-trading system in the EU is expected to have an upward effect on the spot prices at the electricity market. The variations of the spot price imply that some types of power generation may change the situation from earning money to losing money despite the increasing spot price. Heavy restrictions on emissions penalise the fossil-fuelled technologies significantly, and the associated increase in the spot price need not compensate for this. Therefore, a market of TEP's is expected to have a significant influence on the electricity spot price. However, the expected price level of TEP's are met with great uncertainty and a study of a number of economical studies shows a price span between zero and 270 USD per ton of CO_2 depending on the participation or non-participation of countries in the scheme.

The price-determination at the TGC market is expected to be closely related to the price at the power spot market as the RE-producers of electricity will have expectations to the total price paid for the energy produced, i.e., for the price of electricity at the spot market plus the price per kWh obtained at the green certificate market. In the Wilmar model, the TGC market can either be handled exogenously, i.e., the increase in renewable capacity and an average annual TGC price are determined outside the model, or a simple TGC module is developed, including the long-term supply functions for the most relevant renewable technologies and an overall TGC quota. Both solutions are rather simple, but to develop a more advanced model for the TGC market seems to be out of scope for handling the interplay with the Wilmar model. The obligation for the TGC market is normally given on an annual basis, i.e., the certificate quota has to be fulfilled within a given year. This implies that to establish a TGC price on an hourly basis throughout the year is not only difficult, but irrelevant as well. The incorporation of model elements representing an annual quota for emission and deriving a TEP price seems more relevant for the Wilmar model.

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Preface

This report is Deliverable 4.1 of the EU project “Wind Power Integration in Liberalised Electricity Markets” (WILMAR). The aim of the Wilmar project is to investigate the technical and the economical problems related to large-scale deployment of renewable sources and to develop a modelling tool, which can be used to simulate alternative solutions providing a firm basis for decision-making by system operators, power producers and energy authorities.

This report describes the application of the two policy instruments, Tradable Emissions Permits (TEP’s) and Tradable Green Certificates (TGC’s) for electricity produced from renewable energy sources in the European Union. The report contains state-of-the-art for the two instruments and discusses the impacts and importance of the two instruments in a liberalised power market. The report further discusses the implications of TEP’s and TGC’s for implementation in the Wilmar model.

This report is edited by Hans Ravn and Rune Schmidt, IMM Technical University of Denmark, based primarily on contributions from Risoe National Laboratory and IER University of Stuttgart.

1 Introduction

The reduction of greenhouse gas (GHG) emissions has during the last decade become an increasingly important issue in the energy and environmental policies of the European Union and its member states. In 2002, the European Union ratified the Kyoto protocol and thereby committed themselves to a common GHG reduction of 8% by the years 2008-2012 compared to the 1990 level. According to the agreed burden sharing within the European Union, the overall EU target is converted into national GHG targets for each of the member states.

In the implementation of these GHG –targets, the exploitation of renewable energy sources plays an important role within the European Union. The White Paper for a community strategy and action plan sets out an overall target of doubling the share of renewable energy sources (RES) contribution of gross inland energy consumption from 6% to 12% by 2010. As outlined in the White Paper, the increased use of electricity produced from RES constitutes an important part of the measures to comply with the targets in the Kyoto protocol but also to serve other goals as security of supply and achieve greater social and economic cohesion within the Community (European Commission, 1997).

Similar to the growing focus on environmental aspects of electricity supply, the process towards a liberalised electricity market has been going on for some years in the EU with the opening of the electricity market for trade. Electricity exchange markets have been established to facilitate electricity trade with full market access for all consumers and cross-border exchange of electricity. At present, almost no new RE technologies can economically compete on their own with conventional energy production technologies and new supportive instruments to promote electricity produced from RES are, therefore, needed. Consequently, these instruments must be compatible with the liberalised market and ensure cost-effective investment in new RE technologies. Thus, in order to reach the environmental goals and to promote electricity from RES, a number of different policy instruments have been introduced, which includes the establishment of a market for Tradable Emission Permits (TEP's) and Tradable Green Certificates (TGC's).

Following the trend for market-based systems for electricity trading, the main core in the TEP and TGC schemes is to use the market forces to promote electricity from RES and to reach the environmental goals. An important feature of the two schemes is, therefore, the possibility of international trading with green certificates and emission permits and is immediate suggestions for instruments of international co-operation. The introduction of new markets for tradable emission permits and green certificates will create two new interdependent products and they will turn interact with the electricity market. How the TEP and TGC markets interact with each other in a liberalised power market context is, however, not a trivial matter. On this basis, the aim of this report is to analyse the interactions between CO_2 emission trading and markets for electricity produced from renewable energy sources in a liberalised market, including description on how to treat these issues in the electricity system model developed in the Wilmar project.

1.1 The Wilmar Project

Wilmar (Wind Power Integration in Liberalised Electricity Markets) is a research project supported by The European Commission under the Fifth Framework Programme and contributes to the implementation of the key action 5 "Cleaner Energy Systems, including Renewables" within the Energy, Environment and Sustainable Development (EESD) Thematic Programme. The key task of the project is to analyse the integration of wind power in a large liberalised electricity system covering the following countries: Denmark, Finland, Germany, Norway and Sweden. The technical and market impacts of a large share of wind power in the North European electricity system will be quantified using a comprehensive model being built in the project.

The modelling and simulation efforts can be divided into two parts. One part consists of an investigation of the issue of system stability, i.e., the wind integration aspects connected to the fast (below 10 minutes) fluctuations in the wind power production, with the use of dedicated power system simulation tools. It includes the analysis of a number of case studies especially selected for large-scale integration of renewable energy generation and with expected potential stability problems.

Secondly, the wind integration ability of large electricity systems with substantial amounts of power trade in power pools is investigated. With the starting point in existing models, an hour-per-hour simulation model is developed, and this modelling tool is used to investigate the technical and cost issues of integrating large amounts of wind power into the electricity system. The model will cover the two power pools: NordPool and European Power Exchange, i.e., Germany, Denmark, Norway, Sweden and Finland. The developed model will be tested by different end-users, including a system operator and a power producer, which are expected to also be users of the final model. Finally, the results obtained will be summarised and used to provide recommendations about the technical integration possibilities, the integration costs of wind power and the organisation of electricity markets and power pools.

This report is especially related to the second part of the project and has the following objectives:

- To establish a state-of-the-art for CO_2 –emission trading and green markets based on a short survey;
- To analyse and develop the modelling relations for the impacts of CO_2 –emission trading and green markets on the spot market price of power;
- To discuss impacts and consequence of CO_2 emission trading and green markets.

1.2 Overview of this Report

Chapter 2 deals separately with tradable green certificates and tradable emission permits and describes the general features of the two schemes. These are described in detail in Chapter 3 and 4 with particular focus on analysing impacts on the spot market bidding. Chapter 5 deals with analysing the interactions between CO_2 emission trading and markets for electricity produced from renewable energy sources in a liberalised market.

2 Emission Permits and Green Certificate Markets within the EU

As previously described, the main idea of establishing new markets for emission permits and green certificates is to lower GHG emissions and to ensure a politically planned deployment of renewable energy technologies under liberalised market conditions. This chapter deals with the general features of a tradable emission permits scheme and tradable green certificates scheme, respectively, and describes some of the most important issues that arise when introducing these two schemes.

2.1 Tradable Emission Permits

In July 2003, the EU agreed to establish a cap-and-trade system to limit CO_2 emissions from the power industry and other energy intensive industries. The main idea of the scheme is to allocate permits of CO_2 emission on companies that are to be traded on a national or international market. The trading element allows companies that have reduced their emissions by more than their allocated permits to sell their "surplus" to others who are not able to reach their target. The overall environmental outcome is the same as if both companies used their allowances exactly, but with the important difference that both buying and selling companies benefited from the flexibility offered by trading.

The cap-and-trade scheme is well established in environmental policy, particularly for the application of technical standards in the field of waste, water and air pollution (ozone and CO_2), but only little experience has so far been gained with regard to CO_2 emission trading. However, with the introduction of the flexible mechanisms in the Kyoto protocol, a growing international market for CO_2 emission trading has emerged and national CO_2 emission schemes have also been introduced in Denmark and Great Britain.

The emission trading system in the EU is to be implemented by 2005 and will be closely related to the flexible mechanisms in the Kyoto protocol. While the CDM or JI mechanisms allow certain flexibility, the price of the tradable permits solely depends on the supply and demand within the ratifying countries. The amount of available emission certificates increases with the amount of participating countries. The demand for certificates depends on the national commitment to climate gas emission reduction. Most of the industrialised countries subject to emission reduction show a demand for certificates while only some can supply a surplus in order to satisfy it. The effects of an emission-trading scheme in the EU, therefore, also depend on the participation or non-participation of other large countries responsible for large amounts of CO_2 emissions. The ratification by major players, such as Russia, Japan, Australia or the US will especially have huge impact on the actual CO_2 abatement costs within the EU.

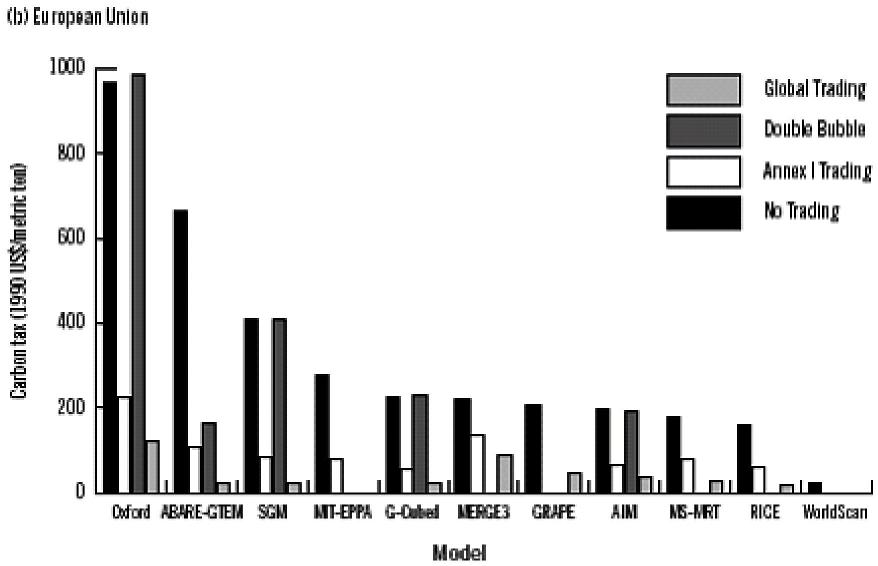
The climate agreement in the Kyoto protocol will only become binding if ratified by countries representing 55% of global GHG emissions and the U.S., which is the largest emitter, with a 37% share, has so far made it quite clear that it will not ratify the Treaty. Australia has argued that the protocol would be ineffective without U.S. participation and it is, therefore, unlikely to ratify. The EU, Switzerland, Estonia, Latvia and Norway, and last but not least, Canada and other countries from, for example, Central Europe and the Baltic together represent 44.2% of total CO_2 emissions and have until now supported the Treaty. Russia, which is responsible for more than 17% of global CO_2 emissions has the remaining vote that determines the fate of the Kyoto Protocol. Even as a former strong supporter of the Treaty, Russia is at the moment unsure of the date of the ratification (Michaelowa and Koch, 2002).

The EU has already decided to honour its commitment and reduce the climate gas emissions as agreed in the early COP and the costs for meeting its obligation depends on the behaviour of the other Protocol parties (Annex 1 countries). The following sub-chapters will try to shed some light into the impacts of different ratification scenarios by screening available studies on this subject. By the withdrawal of the US from the protocol, the impacts of a participation or non-participation of the US is well documented in the scientific community. However, alternative scenarios are not common and, therefore, plausible considerations are undertaken.

2.1.1 The Baseline Scenario

A baseline scenario for comparison with possible trading schemes is chosen for this study. This is the scenario where emissions are traded only within the EU member states and not with other Annex I countries. In the aftermath of the initial Kyoto agreement, many economic modelling studies hinted at carbon prices of several hundred dollars per ton of carbon ($/tC)[1] where there is no trading between countries down to the order of 100 dollars per ton of carbon (approximately 27,3 $/t$CO_2$) in the case of unrestricted trading amongst the industrialised countries (Weynant, 1999).

Considering trading only within the EU implies that the costs per ton of CO_2 to meet the European Union emission caps result from marginal abatement costs in countries with only limited savings potentials. Assuming that the carbon intensity of energy conversion technologies and installed capacities does not differ significantly within the EU, it seems feasible to conclude that abatement costs will be high. Although a small saving may be achieved by trading within the EU, without international trading and also excluding CDM and JI outside the EU, the conclusion of relatively high abatement costs is validated by most of the applied energy models. While the traded amounts within the EU are not explicitly specified in the studies, it seems obvious that countries with a high commitment will buy emission certificates from countries with lower caps. As to the amount of traded certificates, no study analyses these amounts in a detailed way. Grubb (2003) presents the score results of models in a concise disposition. The resulting prices for carbon differ to a high degree, but all results hint at a common finding (see *Figure 1*).



Double bubble: trading within the EU No trading: reduction targets have to meet on national level
(Grubb, 2003)

Figure 1: Impact of international trading on abatement costs.

1 Within the UNFCCC and the private sector, the main indicator resulted in prices for carbon dioxide instead of prices for carbon. The conversion factor between a ton of carbon and a ton of CO_2 is 44/12.

Trading within the EU, but not with another Annex 1 country will result in comparatively high prices per ton CO_2 and only slightly below a scenario where no trading is at all foreseen.[2] The price per ton of CO_2 ranges from 270 to 45 USD (*Figure 1*), depending on the study. It has to be noted that these studies do not generally include carbon sinks, non-CO_2 gases, CDM, negative cost options or ancillary benefits. Therefore, the actual resulting costs might be well below the above-mentioned cost range.

A trading scheme that does not extend beyond the EU would have a significant impact on the economic competitiveness of the emission intensive industries of the member states. Assuming that a solitary trade within the EU implies a non-ratification of the Kyoto Protocol by other industrialised countries, the competitive situation of member states' industries would become increasingly difficult. High costs for abatement or production cutbacks in emission intensive sectors would be the consequence of a non-trading beyond EU borders.

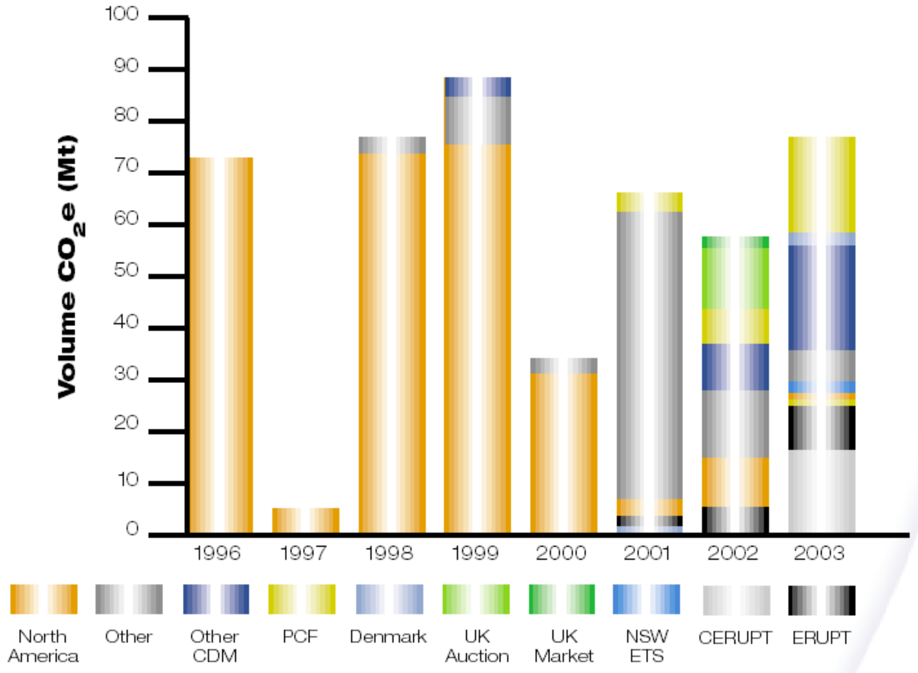
A study by Zhang (2001) presents much lower levels of national prices for emission permits in the case of block trading within the EU and no international trading. Zhang argues that official projections of GHG emissions in 2010 by most EU member countries are very close to their targets (Zhang, 2001). Model results from Zhang project a price for emission rights of 9.1 USD/t CO_2. It has to be ascertained that a segregate emission reduction in the EU with no further international participation by countries with a major share in worldwide emissions would not only lack ecological effectiveness, but it would also imply a high burden for the industries of the EU member countries and its products on the international markets.

	Depending on Study
Certificate Prices	9.1 – 270 USD/t CO_2

An established EU carbon market already trades futures for emission rights of the years 2005-2007. Prices of trade closures indicate a price for emission certificates of 13 €/t CO_2. Chances are that these prices might lower even more with inclusion of CDM and JI.

The volume of emission certificates possibly traded in the first Kyoto period is not clear. A considerable amount of CO_2 emissions has already been traded within the EU in the past years (see *Figure 2*). Point Carbon (www.pointcarbon.com, 2004) has estimated the EU emission trade volume - the EU Allowances Market - for the upcoming first period 2005-2007 of the European Emission Trading System (ETS) to increase from around 190 Mt CO_2 in 2005 to over 900 CO_2 in 2007 (2006 about 580 CO_2). It is expected that the amount of traded CO_2 in the ETS will reach approximately 1,200 million tons in 2010, corresponding to approximately 46% of the Community's 2010 CO_2 emissions.

2 Except for the ABARE-GTEM model, no other model shows differing results and most models do not necessarily analyse the case of block trading.



(www.pointcarbon.com, 2004)

Figure 2 Traded Volumes of CO_2 in Europe in Mt per year in different trading schemes.

2.1.2 Scenario: Russia ratifies the Protocol

While the case of ratification only by the EU shows result in a high certificate price and only limited amounts of traded certificates, these amounts change significantly when Russia ratifies the protocol. Both Ukraine and Russia experienced a dramatic downturn in production after the breakdown of the former USSR and this downturn is also reflected in the CO_2 emissions.

The protocol requires the Russian Federation and Ukraine to stabilise their emissions at 1990 levels. However, due to the economic decline, a yearly surplus of 400 Mt carbon, normally referred to as *"hot air"*, accumulated in these countries during the last decade. Their greenhouse gas emissions dropped by 39% between 1990 and 1998. The main reason for this downturn was identified to be the economic disarray which followed the collapse of the former Soviet Union and central (economic) planning system (Victor *et al*., 2001). Russian experts estimate that about 60 or 70% of the reduction in the energy sector was due to the economic decline, about 8 to 12% to the initiation of institutional reforms in the energy sector and the rest to the substitution of fossil energy carriers through gas and other structural changes in the economy (Mastepanov *et al*., 2001). The Russian Federation could actually increase the emissions by 43% and even the Ukraine has a potential of 83% emission increase thereby still meeting the Kyoto emission targets. The *'hot air'* of both Russia and the Ukraine implies a huge surplus in terms of available certificates and thus a very high trading potential. Without participation of the USA in a trading scheme and only the EU as trading partner, this would imply a certificate price of nearly zero. This is due to the fact that the required CO_2 reduction during the first commitment period, 2008-2012, would be less than or at least close to the carbon surplus in Russia, Ukraine and Eastern Europe. However, Russia and Ukraine could be the dominant sellers of emission permits and they can by withholding their carbon surplus from the market increase the permit price. By considering the possibility that Russia and Ukraine could act as oligopolies, the expected carbon certificate price and traded amounts has to be estimated for two cases; firstly, the case competitive Annex 1 trading and secondly, the Annex 1 Former Soviet Union acting as oligopolies.

- As to the first case, it is assumed that the trading market is competitive, but the US does not ratify the protocol. With US absence from international trading, the largest potential buyer of certificates has disappeared. Therefore, a lessened demand for permits results in a lower permit price. In

(Persson and Azar, 2002), the total emissions in 2010 for the Annex 1 region (excluding the USA) is roughly as high as the Kyoto target and, therefore, the required carbon tax, or permit price, drops to close to zero USD/tC. The transfer of emission permits extends from the economies in transition EiT (the former Soviet Union and the middle and East European countries) to the EU, the pacific OECD countries and Canada. The revenues from trading would decrease close to zero in the Russian Federation and Ukraine as a result of the decrease in permit price. Other studies – as well as common economic sense – confirm these results.

- Russia and Ukraine can be expected to be dominant sellers of emission permits in 2010. Russia and Ukraine have, therefore, strong incentives to act as oligopolies, if the US were not to participate and permit prices fall. The former Soviet Union countries could then decide to sell fewer certificates than in the competitive trading situation and increase the permit price from zero to a positive value. The potential revenues of the Annex 1 EIT countries are very sensitive to the permit price. Persson and Azar (2002) use an energy-economic optimisation model to estimate certificate permit prices and traded amounts. If no abatement policies are implemented in the former Soviet Union, these countries can still sell the difference between their reference CO_2 emissions and their commitment (their "hot air") – about 220 MtC/yr – but then the permit price would basically drop to zero. This would be the case if Russia and Ukraine would allocate emission rights to companies and if they would give allowance to the companies to sell the certificates internationally without any restrictions.

However, Persson and Azar show that by oligopolistic behaviour, Russia and Ukraine would maximize their revenues by restricting the tradable certificates to an amount of 140 MtC/yr with a resulting certificate price of roughly 45 USD/tC. The resulting revenues are estimated to be approximately 6,3 billion USD per year from 2008 to 2012. This presents approximately 15% of the revenues to the present Russian national budget. If, however, the price would increase to above 75 USD/tC, there would be no economic incentive for European countries to purchase permits from the former Soviet Union.

Table 1: Prices and amounts of CO_2 with free trading and oligopoly, respectively

	Free Trading	Oligopoly
Certificate prices	Close to zero	12.3 – 20.5 USD/t CO_2
Traded amounts	806.7 Mt CO_2/yr	513.3 Mt CO_2/yr

2.1.3 Scenario: Emission Trade also with Japan and Australia

This chapter will deal with the effects on the economies, prices and amounts of traded permits in the case that Japan takes part in the emission trade. Additionally, the chapter will give an impression on the possible effects of ratification by Australia, although in less detail.

By still excluding the US from the agreement, the impacts of ratification by Japan have to be estimated. As was stated in the preceding chapter, the "*hot air*" supply by the former Soviet Union is seen as sufficient to comply with the Kyoto commitments. Annex 1 countries can, without own reduction measures, meet their goals by buying Russian or Ukrainian certificates. The high supply of certificates in itself would result in prices not far above zero. Alas, even the minimal certificate prices pose an (however small) impact on the prices in the emission intensive industries and, therefore, impose drawbacks in international competitiveness in comparison to countries not bound by the protocol in their emission activities (like the USA). Studies dealing with the Japanese role thus concentrate on the possible impacts of a non-ratification by the US instead of dealing with the possible impacts of non-compliance of Japan or other small countries. A notable study by Hamasaki (2001) deals solely with the comparison of the economic impacts on different world regions between two scenarios: compliance or non-compliance with regard to the Kyoto protocol by the USA. While those effects are modelled elaborately, there is no study available analysing the distinct economic consequences of a non-ratification versus a ratification of the protocol by Japan. With Japan ratifying, the demand for certificates will be slightly higher as Japanese industries/companies seek to fulfil their reduction goals. With higher demand, the traded amounts of certificates will rise (assuming that the former Soviet Union has enough "*hot air*" to sell) and the price might slightly increase. With a higher price of the emissions certificates, the economic impact of the Kyoto protocol reduction commitments will become more significant, but with further non-ratification of the US, those impacts might be less substantial than feared. However, if Japan had not signed the Treaty, the demand for certificates would have dropped even further and the impacts especially on the European economy might have lessened even more. Hamasaki (2001) analyses the impacts of the Kyoto ratification for different economic sectors.[3] The impact of the ratification of the protocol and of taking part in emission trade by Japan on the EU on the emission price is not covered in the economic literature. It can be assumed that the demand for certificates will increase by 214.4 Mt CO_2/yr as Japan's emissions went up to 1,386.3 Mt in the year 2000. Following Kyoto, Japan has to reduce its emissions to a level of 1,171.9 Mt CO_2 in 2008-2012 (cf.Table 2). Without Russian ratification, prices will probably increase while traded amounts will decrease due to lack of supply.

Australia already stated that it would not ratify the protocol. The theoretical implication of ratification and the economic impacts can nevertheless be estimated. Although Australia was granted an increase in emissions, it seems feasible to assume that Australia would count to the demand side countries for emissions certificates. By joining the protocol, the price for certificates would, therefore, increase. As there is no easily available literature on economic impacts of ratification or non-ratification by Australia, we will not give quantitative estimations.

Table 2: Demand for CO_2 certificates in Japan

	Free Trading
Traded amounts	Increased demand of 214.4 Mt CO_2/yr

2.1.4 Scenario: Inclusion of China resp. Some Developing Countries

China poses a special issue and has to be analysed in more detail than, for example, Australia. As China is not one of the Annex 1 countries, it does not have a reduction commitment stemming from the initial protocol or succeeding COP agreements. However, China possesses a high reduction potential even considering the huge economic growth in the country and at the World Summit on Sustainable Development in Johannesburg, it announced to ratify the Kyoto protocol. With an outdated energy economic and power generating capacity with enormous emission intensities, China proves to be a highly interesting country for JI or CDM measures. The inclusion of non Annex 1 countries in international trading is another possibility to further lessen the costs of emissions abatement in the Annex 1 countries. A study by Zhang (2001) investigates the impacts of different trading schemes by first considering a case where the Annex 1 countries must individually meet its Kyoto targets. The analysis then scrutinizes a scenario of Annex 1 trading and, finally, the case where also developing countries, including China, join in the emissions trading. In the following, the findings of the study are summarised. To guarantee a comparability of the results, the scenarios of the study are reproduced.

In the case of no emissions trading, marginal abatement costs are estimated which then represent domestic prices of permits in 2010. The costs for the European Union presented in (Zhang 2001) are very low compared to estimates from (Ellerman and Decaux, 1998) or (MacCracken et al. 1999). Zhang reasons that official projections of baseline GHG emissions in 2010 by most EU member countries are very close to their respective targets. Thus, the EU only needs to take little additional abatement actions to meet its target and leads to a very low marginal abatement cost in the EU.

3 Note that Hamasaki only considers the case of ratification or non-ratification of the US and does not elaborate on the ratification or non-ratification of Japan itself.

Table 3: Autarkic marginal abatement costs in the no trading case and domestic prices and the international price of permits in 2010 under the three trading scenarios (at 1998 US$/ton of carbon)

Scenarios	United States	Japan	European Union	Other OECD	Eastern Europe	International Price
No emissions trading	160.1	311.8	9.1	33.4	4.5	-
Annex 1 trading*	40.7	40.7	40.7	40.7	40.7	40.7
Trading without China*	18.6	18.6	18.6	18.6	18.6	18.6
Full global trading*	9.6	9.6	9.6	9.6	9.6	9.6
* including the USA						

(Zhang 2001)

Aside from the EU, non-emission trading scenario imposes very high abatement costs in the industrialised countries as was to be expected. Eastern Europe shows a very low marginal abatement cost as well, which is due to the amounts of "*hot air*" especially in the former Soviet Union. Annex 1 trading reduces the domestic certificate price for the US and Japan while it increases sharply in the EU and Eastern Europe. Broadening the trading market brings down the certificate's price further, thereby generating benefits for highly industrialised countries. For the EU, Zhang expects higher costs in the case of Annex 1 trading compared to the autarky situation. The certificate costs reduce to near autarky levels only by inclusion of developing countries and China.

It has to be noted that the inclusion of developing countries broadens the market for emissions rights, and the former Soviet Union will become worse off as the supply in certificates rises. The potential conflict of interest between the former Soviet Union and developing countries will become more important as the Kyoto process proceeds. However, an inclusion of developing countries and notably China with their supply of tradable emission rights into the protocol could provide additional incentives for the USA to move back to Kyoto. The lower price of certificates by way of inclusion of China or other developing countries would satisfy domestic political requirements in the US and also allow the US to reap high benefits from a large joint emissions market where the permit price would be low (Carraro, 2002). By excluding the USA, prices would then drop considerably.

	China Participates in Trading	Developing Countries except China Participates	Solely Annex 1 Trading
Certificate prices	9.6 USD/t CO_2	18.6 USD/t $_{CO2}$	40.7 USD/t CO_2
Traded amounts	++	+	0

++: highest; +: high; 0: baseline with full Annex 1 trading

2.1.5 Participation or Non-Participation of the US

The withdrawal of the US generated a strong interest in the quantitative and qualitative impacts of a Kyoto protocol without US participation. The government of countries, which ratified the Kyoto agreement or are in the process of committing their countries to the reduction targets fear for inequalities for their competitiveness and the danger of inefficiency of the protocol itself. The refusal by President Bush to sign the protocol in order to protect the American economy will have a huge impact on the effects of the emissions certificates' prices and traded amounts. The US rejection of Kyoto removed by far the largest potential source of demand for emissions rights in the Kyoto system. The result is to leave a large potential supply by the economies in transition (esp. the former Soviet Union) set against a radically reduced demand. The impact on the price and traded amounts of emissions permit is, therefore, obvious: both will fall drastically.

Table 4 summarises the results of various economic modelling studies conducted since the US withdrawal from Kyoto. Without exception, US withdrawal has a big impact in these models, which mostly assume a freely operating international trade in allowances and, in some cases, pushing the permit price close to zero. All models show at least a halving of the permit price in the case of non-ratification by the US. The resulting certificate price ranges – depending on the study – from close to zero in the case of a non-ratification by the US up to 40.7 USD per ton CO_2 (Zhang 2001).

Table 4: International carbon prices from Economic models of the Kyoto system – US participation or withdrawal

	Equilibrium Carbon Price, \$/t CO_2		Price Impact of US Withdrawal
Model/Study	With US	Without US	(Decline in %)
Hagem and Holtsmark (2001)	15	5	66
Eyckmans et al. (2001)	22	10	55
Den Elzen and Manders (2001)	37	13.6	63
Böhringer (2001)		Close to zero	88-100*
Babiker et al. (2002)	10	Negligible	
* depending on inclusion of carbon sinks			

Another study by Springer (2002) also shows resulting prices with values between zero and 12 USD/tCO_2, without giving an indication of the prices in the case of US compliance with Kyoto. Hamasaki (2001), which also analyses the sectorial economic impacts within the US, EU and Japan. Towards this end, Hamasakis model defines 10 sectors, mainly energy intensive industries (coal, oil, gas, electricity, etc.) with an additional agricultural and servicing sector and a regional aggregation of 8 regions. The regions include amongst others the US, Japan, the EU, former Soviet Union and China. The results of the model are given in percentage changes of production output in each country (region). Table 5 gives an overview over some of the model results.

Table 5: Model results; production output change in EU, Japan and the USA

	Without US Ratification of the Protocol			With US Ratification of the Protocol		
	JPN	USA	EU	JPN	USA	EU
COL	-3.63	-2.03	-12.49	-9.26	-29.36	-16.96
OMN	-0.26	0.05	-0.39	-0.29	-0.69	-0.29
AGR	-0.25	0.08	-0.35	0.06	-1.99	0.06
COL : Coal; OMN: metals nec, mineral products nec, paper products and publishing, other manufacturing, trade and transport; AGR: agriculture, forestry and fishing						

(Hamasaki, 2001)

In the case that the US does not ratify the protocol, Table 5 shows an increase of the production in the US manufacturing industry while on the other hand, production in those sectors shrinks in Japan and the EU. The main reason is that the US industry does not have to bear additional expenses by the reduction of greenhouse gases. The EU and Japan have to meet their Kyoto targets and will thus bear additional expenses and lose international competitiveness to those countries that have no emission reduction targets in place. Especially the US energy sector experiences huge benefits. In the case that the US ratifies the Kyoto protocol, the domestic energy consumption will have to decrease sharply; this is represented by the sharp decline in the coal sector. The EU competitiveness in terms of trade and manufacturing of other goods experiences some relief. Especially the agricultural sector benefits from US ratification. However, the rising price for tradable permits also burdens the EU energy sector more than in the case of non-ratification by the USA. With increased demand for certificates, the relatively cheap (in the case of non-ratification by the US) supply from the former Soviet Union becomes increasingly more expensive.

Other model based calculations show expected permit prices under full global trading, including the USA to be between 1 and 25 €/tCO_2 and under Annex I trading between 3 and 78 €/tCO_2 (trading including the US). Table 6 illustrates some of the model results.

Table 6: Model based calculations for permit prices; acc. to Varilek & Marenzi, 2001

Permit Prices in 2010 under full Global Trading (€/CO_2) incl. USA	
Rose	1
POLES	7
GEM E3	9
MERGE	25
Permit Prices in 2010 under Annex I trading (€/CO_2) incl. USA	
Rose	3
GEM E3	18
Poles	19
GREEN	20
GTEM	40
Oxford	78

In general, the range in carbon prices in the models reflects the differences in presumptions made. Prices are affected by several factors including:

- The stringency of caps placed on Annex I countries;
- The limits on trading, such as supplementary requirements, fungibles;
- Availability of JI and CDM projects for investment;
- Number of players active in the market (i.e., will USA participate or not);
- Technological options to reduce emissions;
- GHG emissions development;
- "*Hot air*" from Russia, Ukraine and other countries with economies in transition (CEIT's) that are likely to have emissions in 2010 that are below their Kyoto targets. Thus, they may have a surplus of allowances. Other possible net sellers are the group of EU candidates in Central and Eastern Europe.

There are clearly considerable uncertainties involved in predicting future carbon prices, but prices are expected to stabilise as the institutional framework governing the mechanisms stabilises. These uncertainties are reflected in the broad range of predicted prices for emission certificates throughout the literature.

	US Non-Participation*	US Participation*
Certificate prices	0 – 13.6 USD/t CO_2	10 – 40.7 USD/t CO_2

*depending on study

2.1.6 Conclusion: Price Development in Different Trading Environment

The analysis of different participation schemes in the Kyoto process shows that ratification by additional countries beyond the EU has a significant impact on the prices and traded amounts of emissions rights. Especially a possible ratification by 'big international players' such as the former Soviet Union with their huge amount of "*hot air*", or alternatively, the USA as the worldwide greatest emitter of greenhouse gases shows an enormous change in the international emissions right prices and traded amounts. Only with Russia and Ukraine ratifying the protocol can it come into force and, additionally, a supply of relatively cheap tradable certificates is guaranteed, i.e., as long as the former Soviet Union does not act as an oligopoly to maximise its profits.

A participation of the US in the protocol is not to be expected after the clear withdrawal and the statement made by the current president, Mr. Bush. However, the non-participation does not only have the effect that the prices and amounts of traded emission rights decrease drastically. It also endangers the whole Kyoto protocol as the former Soviet Union countries are bereft of the expectedly best customer for certificates.

Trading for the EU, which already submitted itself to following their Kyoto commitment, as was shown with the new directive on a European Trading Scheme – ETS – will commence in 2005. The possibility that the Kyoto protocol might not come into force or the different participation schemes of other countries only has one effect: how high will the costs of complying with their commitment be? Allowing for ratification and for the Kyoto protocol to come into force means that international trade with certificates might lessen the burden within the EU. Without US participation, there will be enough "*hot air*" and cheap certificates available as long as Russia and Ukraine ratify for the EU to fulfil its commitment. But if the former Soviet Union decides to follow the US example and not ratify the protocol, the costs of meeting the goals will inevitably rise. By including developing countries and especially China into the trading schemes means that the costs will decrease further; even if the US would overthrow their decision and decide to join. Even the high demand for certificates in the case of US participation can be satisfied at a relatively low price with the developing as part of the Annex 1 trading.

2.2 Tradable Green Certificates

In the promotion of renewable energy technologies, the European Commission has launched a directive on the share of renewables in the individual member states in 2010, based on the percentage of each country's consumption of electricity. Although not binding, it seems that these targets are by now accepted by the EU member states (European Commission, 2001).

Within quite broad limits given by the EU, the Member States can today choose for themselves which support scheme to use in order to implement the above-mentioned renewable targets and among the EU member states opinions differ on which support system is the most efficient to be used. Germany, Spain and France have decided to stick to the well-tried feed-in tariff system for supporting their renewable technologies, while countries such as Sweden, Italy, the UK and Belgium have introduced tradable green certificate systems, although the certificate systems differ considerably in the way they are implemented in these countries. Thus, no common EU TGC-system seems to be underway within the next year.

2.2.1 The TGC Approach

A system of TGC's can be characterised both as an accounting system to certify the electricity production from renewable energy sources and as a regulatory instrument to ensure a politically planned deployment of renewable energy technologies. In a system of green certificates, the RE-producer sells electricity to the grid, and at the same time receives a certificate for each pre-defined unit of electricity produced. Since electricity from RE and conventional production cannot be distinguished from one another, both are sold in the physical power market. The green certificates are financial assets and can be traded at a green market separated from the physical market and added to the revenue that the producer can receive for the electricity itself at the physical power market. Thus, the price obtainable to the RE-producer will be the sum of the market-based settling prices for physical power and green certificates.

The demand for green certificates is driven by a politically determined goal for RE consumption, e.g., the national indicative targets. The demand for certificates is induced by transferring the national indicative targets for RE to either the consumers and distribution companies or the supplier of electricity who will have to prove that they respectively consume or supply at least the specified amount of electricity produced from RE. In most countries, the obligation is imposed on the consumers and distribution companies, but in Italy, the obligation is imposed on every supplier of conventional energy, who is required to ensure that 2% of the electricity delivered to the grid is produced from RE. Hence, the suppliers will have to install new RE-capacity or buying certificates and in the remaining, suppliers of energy are also referred to as consumers of green certificates.

2.2.2 Minimum and Maximum Prices

In order to reach the goal of RE, the TGC scheme often contains a penalty for consumers who are failing to fulfil their targets (e.g., buying the minimum required certificates). In this way, national governments signal the maximum price they are willing to force unto consumers to pay for the deployment of renewable energy sources. Thus, if the market-based price of TGC's exceeds the penalty, the consumers will prefer to pay the penalty instead of TGC's. Likewise, the penalty also sets out the maximum price to the owners of RE generation technologies as it functions as a price cap for the TGC's. In order to provide more certainty for investments in new RE-capacities, some TGC schemes also operate with a minimum price that ensures sellers of TGC's to receive at least a minimal additional income from the green certificates. Thus, the minimum price thereby works to reduce the downward pressure on TGC prices in years with excess supply.

If an international market for TGC's is established, different national price-caps will converge into one. With different national maximum and minimum prices, TGC's will be traded at prices below the lowest penalty and above the highest minimum price. At present, Belgium (the Flanders region), Denmark, Italy, Sweden and probably also the UK have introduced or are planning to introduce a price-cap on the TGC market (Nielsen and Jeppesen, 2003).

2.2.3 Validity of Certificates

One important issue in order to establish a common market of TGC in the EU is the validity of certificates. In Italy, the green certificates are valid for the reference year only while in Denmark and the Netherlands, the green certificates have no date of expiry. This implies that Danish and Dutch suppliers of green certificates can withhold certificates in years with excess supply and low prices and sell them in years with a supply shortage and higher prices. Likewise, consumers can buy certificates in years with excess supply and low prices and use them in years with low supply. Consequently, different certificate validities will restrict trade of TGC's in an international market because different periods of validity cannot co-exist.

2.2.4 Tradability of Green Certificates

Another important issue to take into consideration in the discussion of TGC's is the tradability of green certificates from the different national TGC systems. One of the ideas behind the TGC approach is to place investments in new renewable energy sources where it is most profitable in order to ensure cost efficiency. Thus, to increase cost-efficiency, the market of green certificates should cover as many different types of renewable energy generation, e.g., electricity, gas, and heat, and also different types of RE-technologies. Whether the green certificates should only be subject to new RE-capacities or also include existing energy production from RE technologies is, however, a question of the purpose of the TGC-scheme. If the purpose is to increase the installation of new RE capacity, the existing capacity should not be included as it can be argued that once installed and financed, the existing RE-capacity is already competitive without the extra financial compensation from the certificate.

A comparative analysis of six national systems of TGC in Europe by Nielsen and Jeppesen (2003) shows that the main focus is on electricity generation, while generation of heat and gas is only included in Belgium (the Flanders region) and the Netherlands. Also, the national definition of RE technologies approved for green certificates is another aspect where the countries differ. In the UK and Denmark it has been decided to exclude large hydropower plants from certification and in the Netherlands, Germany, the Flanders region, and Denmark, non-organic waste is to be excluded. Furthermore, in Italy, it has been decided that existing plants (with a few exceptions) are ineligible for certification and that new plants receive certificates for the first 8 years of production only. Contrary to this are the Flanders region and the Netherlands, where existing plants are eligible for certification along with new plants.

In order to establish a common market of TGC in the EU and to trade green certificates across borders, the different countries must agree on a common definition of certified technologies and which sectors to include in the system.

3 TEP Influence at the "Joint" Market Bidding

In this chapter, the main characteristics of a tradable emission permit approach will be outlined and the implications of a TEP-scheme on the systems simulations in the Wilmar model will be discussed.

The major characteristics of a CO_2 emission-trading scheme are:

- A cap is set on the total emissions of all participants in the scheme by allocating a certain amount of emission permits, which is fixed ex ante for a certain period. The permits are tradable and can be freely traded among the participants;
- Participants are obliged to surrender a quantity of permits equal to their emissions over a certain period. A surplus of permits can be sold (or banked), while a deficit has to be covered by purchasing additional permits (or paying a penalty);
- The obligation to surrender permits is imposed on the generators of electricity using fossil fuels.

3.1 Bidding at the Spot Market

The Nord Pool Elspot market is a day-ahead physical-delivery power market where the price of power is based on supply and demand. The products traded on the Elspot Market are bids of a one-hour duration, block bids and flexible hourly bids and the deadline for submitting bids for the following day's delivery hours are 12 noon. For each hour, the market clears (equalises supply with demand) and the price is determined at spot market. If there are no limitations of transmission within the market, the spot price will be the same in all areas.

In theory, the supply of power at the spot market is determined by the marginal costs of power production. Typically, the bids from hydro and wind power enter the supply curves at the lowest level, due to their low marginal costs, while bids from conventional condensing power plants have the highest marginal costs and enter at the high end of the supply curve.

Power producers will generate electricity when the spot price is highest and cover the marginal costs of power production. Hence, in periods with high demand, the power producers will try to maximise production. In principle, all power producers can trade at the Nord Pool exchange market, but in reality only large producers act on the market. In Denmark, the Transmission System Operators (TSO) is obligated to buy all electricity produced from renewable energy and decentralised CHP (priority dispatch). The Wind producers are paid a feed-in tariff for everything they produce and decentralised CHP are paid according to a three-level tariff and this implies that these producers do not react on the price signals from the spot market.

3.2 Influence of TEP on the Spot Price

The CO_2 emission-trading system that is to be launched in the EU may have a significant impact on the price of electricity as all producers of electricity based on fossil fuels may face additional costs of purchasing emission permits. In order to stay within their specified quota, they will be faced by higher marginal cost of power production because they will either have to carry out measures to abate CO_2 emissions or buy permits to cover their emissions. Thus, the influence of an emission-trading system in EU on the spot price will depend on the allocation of permits for the electricity sector and the prices of TEP.

3.2.1 Allocation of Permits on the Electricity Sector

The amount of permits allocated for the electricity sector is a crucial factor in order to estimate the influence of the CO_2 emission trading on the spot price of electricity. Consequently, if producers of electricity are only given small amounts of emission permits, they are forced to buy more permits than if they were given a greater amount.

The EU directive on CO_2 emission trading states that 95% of the permits must be allocated for free in the first period from 2005-2007. The directive also states that the amount of permits must be in accordance with the national targets of the Kyoto protocol in each member states. However, the actual amount and allocation of permits are a matter for the individual member states.

At present, several countries have submitted their national allocation plans of emission permits to the EU. In general, the allocation of emission permits is based on the principle of grandfathering, e.g., historical emissions. In the EU, approximately 95% of CO_2 emissions originate from fossil fuel combustions and the energy sector is, therefore, in particular subject to the allocation of emission permits.

3.2.2 TEP Prices

The influence of a EU emission-trading system on the spot price of electricity will be highly dependent on the market price of TEP. As described in the previous chapter, a great uncertainty is connected to the expected prices of TEP's that range from close to zero up to 270 USD per ton CO_2. Consequently, the influence of the TEP costs at the spot price will be less in an emission-trading scheme that is open to international trade than a scheme that only includes the EU.

In a study by Hindsberger *et al.* (2003), the consequences of different CO_2 emission limits on the spot price in the four Nordic countries has been analysed. The results show that a low CO_2 emission quota (TGC1), for example, to the four countries' targets in the Kyoto protocol, the spot price will increase from the present level with up to about 50% in 2010. As shown in Figure 3, the highest prices will appear in Denmark and Finland and the lowest in Norway and Sweden.

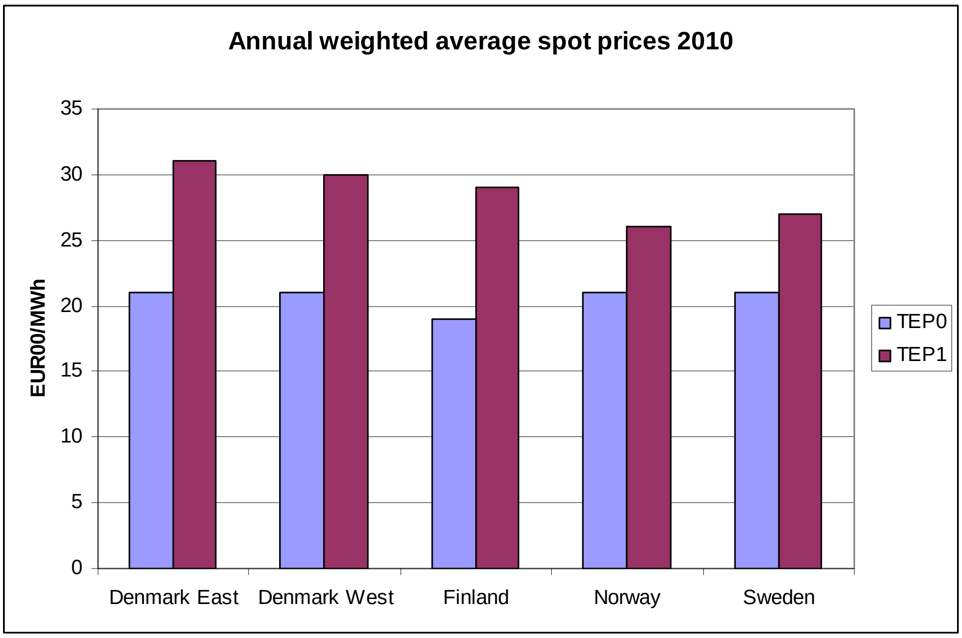


Figure 3: Annual weighted average spot prices 2010.

In respect of the producers' surplus, the picture is complicated. The surplus gained by the owner of a particular production unit depends on the cost of production (and for new investments also on investment costs) and on the price of TEP's. For production units with emissions, the relevant prices are the spot price and the TEP price, and for production units that have no emissions (e.g., renewable energy), the relevant price is the spot price only. Hence, the various types of production technology will be quite differently affected as illustrated in Figure 4. The graph, which refers to the situation in Sweden, shows the variable production costs for different types of technology in two cases: no emission limitation (TEP0) and maximum emission limitation (TEP1). Since the cost of acquiring the necessary TEP's associated with production is internalised into the electricity production cost, the cost will increase for the production types that have emissions.

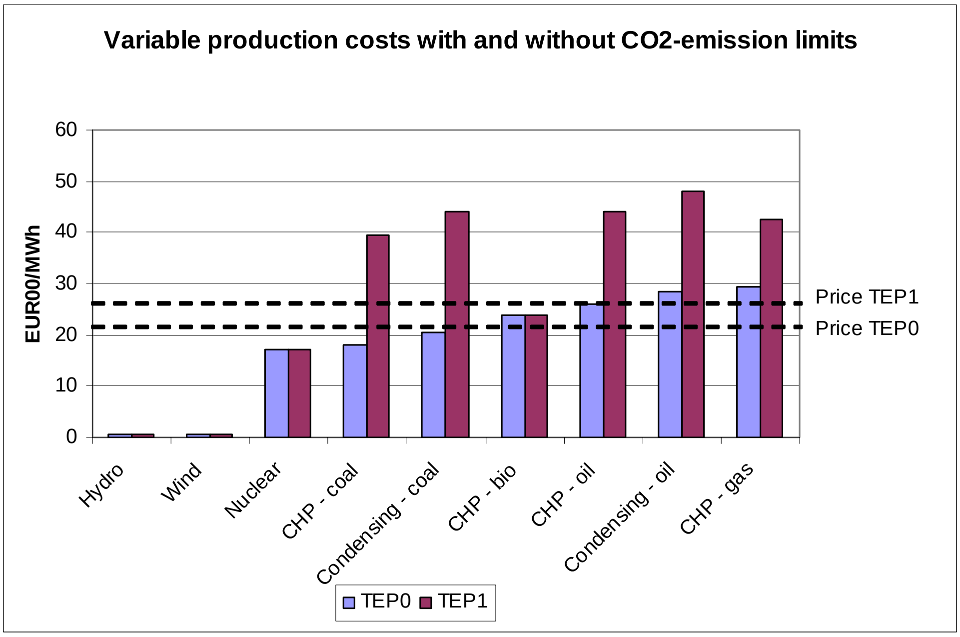


Figure 4: Variable production costs with and without CO_2 emission limits in Sweden.

The figure also shows the electricity spot price in Sweden with and without the CO_2 emission limits. As seen, the variations on the spot price imply that some of the technology types may change the situation from earning money to losing money, even though the increasing spot price is shown as the dotted horizontal lines. Heavy restrictions on emissions penalise the fossil-fuelled technologies significantly, and the associated increase in the spot price does not compensate for this. For non-emitting technologies (renewable and nuclear), the cost is not affected by emission limitations, but the income is.

4 TGC Influence on the “Joint” Market Bidding

In this chapter, the main characteristics of a Green Certificate approach will be outlined and the implications of a TGC scheme on the systems’ simulations in the Wilmar model are discussed.

4.1 The Green Certificate Market – the Long Term Concept

As mentioned in chapter 2, the idea of a TGC approach is to use market forces to determine the necessary additional payment to investors in renewable plants. Thus, at the core of the TGC market is a certification of all renewable produced energy and an obligation to buy these certificates (Morthorst 2000 and 2003 a):

- All renewable energy technologies, including wind power, biomass and biogas plants, photovoltaics, geothermal and small hydro plants, are certified for producing green electricity. The owners will receive a green certificate per unit of electricity produced (per MWh);
- Producers or consumers of electricity are obliged to buy a certain share of their production or consumption as electricity generated by renewable energy technologies. Buying the above-mentioned green certificates from the owners of renewable technologies can fulfil this obligation;
- The Energy Authorities will determine this share (quota), presumably for a number of years in advance. At the end of each year, a volume of TGC’s corresponding to the quota will be withdrawn from the market by the authorities;
- If the actors at the market cannot fulfil their quota-responsibilities, penalties have to be paid for the deficits of certificates.

The green certificates will be supplied to the market, partly by already existing renewable plants, i.e., plants established before the considered timescale, and partly by newly established ones. At the core of the certificate market, approach is a regulated development of new renewable capacity. Thus, it is important that the quota is set in such a way that after subtracting the supply of certificates by existing renewable plants from the given quota, it should then be possible to cover the residual demand for certificates in the given timescale by newly established capacity. The increases in quotas over time will have significant impacts upon the expected future price of certificates, which are of utmost importance for potential new investors in renewable capacity.

The long-run marginal cost of renewable produced electricity is the core in the long-run supply of certificates, where the long-run marginal cost is defined as the cost per unit of energy produced (per kWh) over the lifetime of the plant, taking into account all the relevant costing issues. Parameters paramount to the decision for establishing a new renewable plant include investment costs, fuel costs, O&M costs, the expected lifetime of the plant and its electricity production and, finally, an appropriate risk premium. The risk premium will to a certain extent depend on technological risk factors as the expected availability of the plant, but most importantly will be economic factors as the expected future production costs of new renewable plants.

The determination of the expected long-run equilibrium price for the green certificates is shown in Figure 5. The supply from existing renewable plants covers part of the predetermined demand for certificates (the quota) and those plants expected to be established in the previous period has to cover the residual part to fulfil the quota. The expected long-run equilibrium price for the development of new renewable capacity (P_e) is determined by the intersection of the expected long-run marginal cost curve for new capacity and the vertical demand line (the quota). As shown in Figure 5, this long-run equilibrium price is divided into a part covered by the spot market price of power and a residual part to be covered by the price of the green certificates. P_e is the starting point for the short-run supply curve. If short-term conditions are in accordance with the expected long-term development, the short-run price of certificates will be equal to the long-run equilibrium price. But if short and long-term conditions differ (e.g., if produced electricity by existing plants falls short of expected production, which will shift the short-run supply curve inwards), the short-run price of certificates will be different from the one given by the long-run equilibrium.[4]

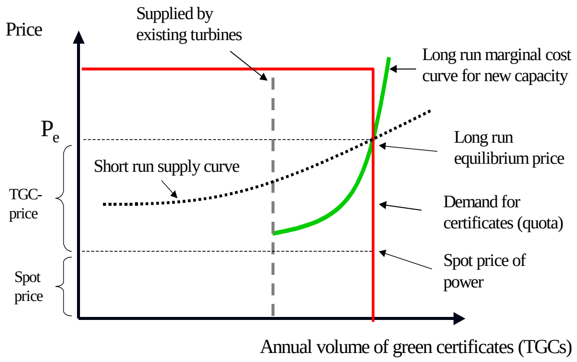


Figure 5: Price determination and the relation between long and short-run in a green certificate market.

A number of reasons might exist for why the long-term equilibrium would not be fulfilled, among these is most importantly that the amount of generated electricity would differ from the expected production. In that case, the supply of certificates is determined by the short-run supply curve, as shown in Figure 5. The shape and slope of this supply curve will be determined by short-run considerations; among these are the suppliers' willingness or aversions to risk, their individual economic situation and expectations to the size of the quota compared to the expected power production. Until now, experiences with green certificate markets using the obligatory quota concept are limited and, therefore, it is difficult a priori to determine the shape of the short-run supply curve.

The income to owners of renewable plants will consist of two parts: one part from the sale of the electricity produced to the spot market and one from the sale of green certificates. The two parts will be traded at two separate markets and the financial certificate market will in principle be totally separated from the physical electricity market. Therefore, for potentially new renewable plant owners, not only the green certificate market will be relevant, but the physical spot market for electricity will be important as well. Price-determination at the TGC market is expected to be closely-related to the price at the power spot market. The potential wind turbine owners will have expectations to the *total* price paid for the energy produced, i.e., for the price of electricity at the spot market plus the price per kWh obtained at the green certificate market. The following parameters are the most important ones in determining the future green certificate prices:

- *Spot Price:* If the spot market price is low, this will increase expectations to the price of green certificates, while if the spot price is high, a lower price of green certificates might be accepted;
- *Certificate Quotas:* If the quotas state a rapid development of new renewable capacity, this tends to raise the certificate-price – in a similar way, a slow development of the quotas will tend to lower the certificate –price;
- *Technological Development:* A rapid development of renewable technologies tends to lower the certificate price; correspondingly, a slow development will give a higher certificate price.

The last mentioned issue implies that efficiency improvements of new renewable energy technologies will directly show up as lower TGC prices and, therefore, result in a lower payment to the owners of renewable plants. Thus, due to the strong connections between improved efficiencies of new renewable plants and the long-run TGC price, the TGC market should in principle make itself redundant in

4 The short-run supply curve in Figure 1 is drawn given the assumption that the validity of certificates is eternal. If the validity were limited to, for example, one year, the curve would look much different.

the long-term (Morthorst 2002). To show how this influences the development of the TGC price over time, the results of an illustrative simulation with a TGC market model is shown in Figure 6.

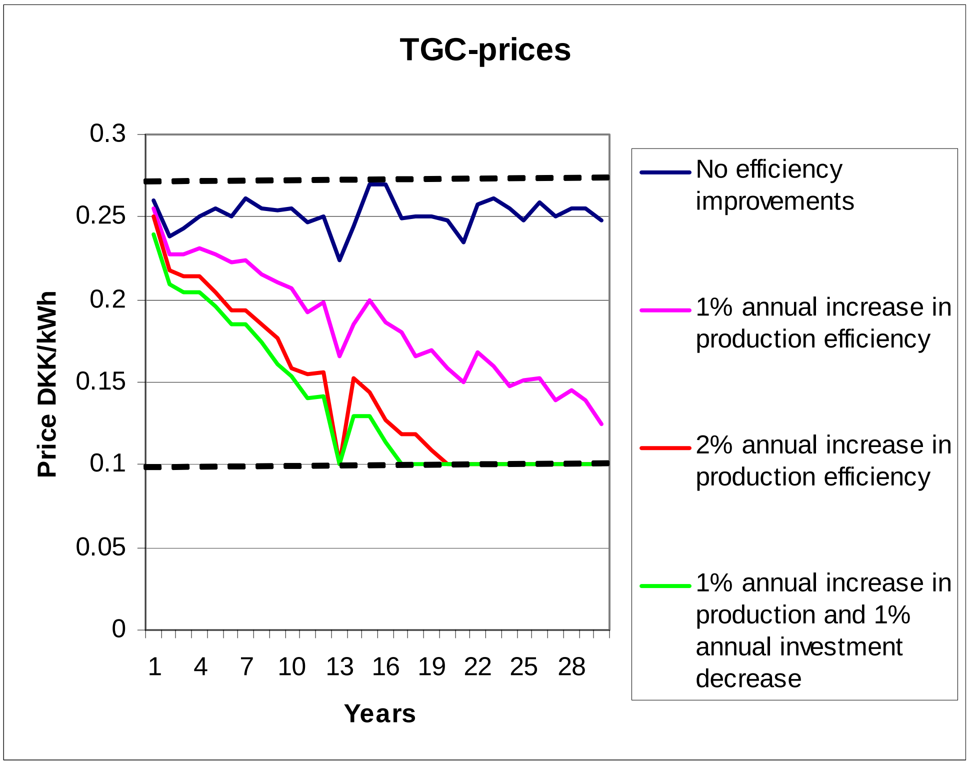


Figure 6: Simulating TGC price developments in cases with different technological development (different efficiency improvements) assuming an upper and a lower price limit.

The starting point for the simulation is the "no efficiency improvement" case. In this case, the simulation is adjusted[5] to follow a path of almost constant TGC prices – the small ups and downs could be removed by a closer fine-tuning of the model, but has no influence on the results. Observe that an upper and lower limit of the TGC price is assumed as in the Danish TGC approach. If energy production efficiency improvements of new renewable plants are assumed, significant reductions in the TGC prices show up as the result. An annual efficiency increase of 2% for new plants would as a result imply that the TGC price would hit the lower limit after approximately 20 years[6]. If an efficiency improvement of 1% p.a. were combined with a 1% p.a. decrease in investment cost, the results would be slightly more positive, because investment costs are reduced up-front.

4.1.1 The Implications of a TGC Market for the Simulations in Wilmar

As mentioned above, the core in the TGC system is to drive new investments into renewable energy technologies. Normally, the TGC market is modelled as an annual equilibrium market, where the growth in renewable capacity is equivalent to the increase in the stipulated certificate quota and the TGC price is determined by the corresponding long-term marginal cost of the renewable technologies minus the power spot price. Thus, the modelled TGC price is an equilibrium price, where neither shortage nor deficits exist in the TGC market.

Wilmar is an hourly-based annual model that does not determine investments in new plants endogenously (Meibom *et al.*, 2003). Because there is no need to determine investments in renewables, there

5 By adjusting the TGC-quota.

6 Assuming that no other barriers would restrict the renewable development.

will be no explicit function of a TGC system in this model, except that the existence of a TGC market might influence the simulations of the power system in Wilmar. Thus, Wilmar is influenced in two ways by a TGC system:

1. Because a larger capacity of renewable technologies is established, the amount of renewable energy produced may be increased and more supplied to the power exchange. This will not only have an impact on power price, but might also influence the technical functioning of the system, for instance, due to congestions of power transmission lines;
2. Owing to the existence of the TGC price, the bidding price of renewable plants into the power exchange might be lower than their marginal costs. Thus, the TGC price might influence the strategy of bidding of the renewable energy producers and, therefore, also the timing of the renewable energy produced.

These two issues can be taken into account in Wilmar, either by exogenously determining a TGC price and the increases in renewable energy produced or by developing a module to Wilmar that on a one-year basis models the consequences of a TGC system.

Thus, if a *EU wide TGC system* was a relevant alternative to investigate, it would be appropriate to exogenously determine the volume of renewable energy produced and the corresponding TGC price, because a major part of the TGC system would anyway reside outside the Wilmar model. This would be the most simplistic way to introduce the TGC market, only implying the exogenously determined supply of renewable produced energy and the adjustment of marginal costs for the relevant renewable technologies.

If only a *TGC system restricted to those countries modelled in Wilmar*[7] were considered, the above-mentioned exogenous approach could still be used, but it could be relevant to develop a separate module modelling a one-year TGC market in Wilmar. This module includes long-term supply functions for the most relevant renewable technologies (wind power, biomass and biogas plants, photovoltaics, geothermal and small hydro plants) and the stipulated development in the national quotas of certificates. The module determines the long-term marginal cost of renewable development corresponding to the certificate quota, and, thus, by subtracting the power spot price, implicitly the TGC price.

Nevertheless, the above-mentioned TGC module would still handle the TGC market in a simplistic manner. A more satisfactorily way of modelling the TGC system is to develop a comprehensive multi-annual model, which over time takes into account how the TGC market develops, including quotas, technologies, price expectations, etc. Moreover, the stochastic intermittencies of wind power and photovoltaics power production might have a significant influence on the TGC price, implying the need to also introduce banking and borrowing in the model. But an advanced model like this one seems not only to be out of scope for handling the interplay with Wilmar, but also such a TGC module would be incompatible with the hourly simulation model.

4.2 The Green Certificate Market – The Short-Term

Wilmar performs a detailed hourly simulation of the power system, including renewables as wind power. This simulation will run basically for one year, but by linking the individual years will, of course, mean that a series of years can be handled. In order to obtain a short-term interplay with the TGC market right, this means that information about the TGC price should be available for each hour of the year in question. This raises two fundamental problems in relation to the TGC market:

- A TGC market normally only has a binding obligation by the end of the year. This means that although the certificates may be traded throughout the year, this trade could in reality be carried

7 Or perhaps only one or a few of the countries modelled in Wilmar.

out just before closing the annual market, implying that no information is available during the year;

- Although trade does take place during the year, there is no explicit demand or supply functions, which are specifically used on an hourly basis. Therefore, what makes actors trade will be a mixture of expectations (among other issues' expectations to the supply of certificates and to the spot price of power), strategy and willingness to speculate (risk takers or risk averse).

Owing to these two issues, it will be difficult, if not irrelevant, to model a TGC price on an hourly basis. It is, therefore, suggested to use the long-term TGC price (estimated as an annual average) as the hourly price for TGC's. This average could eventually be adjusted by a stochastic factor, determining a certain random variation of the TGC price on an hourly basis.

4.3 Conclusions and Recommendations

Quite a number of Member States within the EU such as Sweden, Italy, the UK and Belgium have introduced tradable green certificate systems. The certificate systems applied in these countries differ considerably in the way they are implemented and cannot be converted directly into a harmonised EU scheme. Therefore, no common EU TGC system seems to be underway within the next year.

The idea of a TGC approach is to use market forces to determine the necessary additional payment to investors in renewable plants. Thus, at the core of the TGC market is a certification of all renewable produced energy and an obligation to buy these certificates. The main intention of the TGC system is to drive forward new investments in renewable energy technologies.

In relation to the Wilmar-model, a TGC market influence the modelling in two ways: 1) A TGC market drives forward more renewable capacity than would have been the case without the market. Thus, more renewable produced energy is supplied to the power exchange. 2) Owing to the revenues from the certificates, the owners of renewable plants might lower their bids to the power exchange below their marginal costs. This might also influence the operation of these plants. In both cases, the simulations of the power system in Wilmar will be affected.

In the Wilmar-model, the TGC market can either be handled exogenously, i.e., the increase in renewable capacity and an average annual TGC price is determined outside the model, or a simple TGC module is developed, including the long-term supply functions for the most relevant renewable technologies and an overall TGC quota. Both solutions are rather simple, but to develop a more advanced model for the TGC market seems to be out of scope for handling the interplay with the Wilmar-model.

The obligation for the TGC market is normally given on an annual basis, i.e., the certificate quota has to be fulfilled within a given year. This implies that to establish a TGC price on an hourly basis throughout the year is not only difficult, but also irrelevant. Therefore, it is suggested to use the long-term annual average TGC price, eventually adjusted by a stochastic factor as the hourly based TGC price to be used in Wilmar.

5 Influence of Interaction between TEP's and TGC's at the "Joint" Market Bidding

In this chapter, we examine some of the effects of the interaction between a market for emission trading and green certificates on the bidding at the physical power market. The chapter describes some of the consequences of implementing two parallel markets of TEP's and TGC's into a liberalised power market.

Although an emission trading system and a market for green certificates for renewable electricity are focused on different target groups, there is an overlap between the objectives of these instruments. Both instruments are aimed at promoting electricity produced from RE although the primary aim of emission trading system is to reduce CO_2 emissions and thereby indirectly encourage the saving of fossil fuel use in general and in particular the switch to renewable energy. Thus, deploying renewable power production is one option for the power companies in fulfilling their CO_2 reduction targets and complying with their TEP quotas.

In the study by Hindsberger *et al.* (2003), the interactions of an international green certificate market and a tradable permits market in combination of a liberalised electricity market is analysed in relation to countries in the Baltic Sea Region. The study has addressed a situation where goals for limitations on CO_2 emissions and/or introduction of renewable energy have been implemented through the establishment of international systems of exchange of TEP's and/or TGC's. Thus, it is assumed that one or two international markets have been established in addition to the electricity market. The situation has been explicitly modelled at two abstraction levels, one suitable for defining and analysing basic functionalities and one (the Balmorel model, www.balmorel.com) suitable for numerical analysis in relation to countries in the Baltic Sea Region. The Balmorel model was taken as starting point for the Wilmar model and the results from the two models are, therefore, comparable. The numerical simulations contribute an estimate of the TEP and TGC prices and spot price electricity in the region depending on the assumptions regarding target setting for renewable energy and emission limitation.

The general conclusion is that within the range of goals stipulated in the EU draft directive (23.6% renewable energy) and the Kyoto targets for emissions, prices are affected significantly: from –2 to +10 EUR00/MWh for electricity spot prices, TGC prices up to 50 EUR00/MWh, TEP prices up to 18EUR00/t CO_2 and up to +15 EUR00/MWh on the consumer costs. This estimated increase will result in increased consumers' cost of electricity in the Nordic countries of up to 6 billion EURO annually and have important consequences for the production and investment patterns in the electricity sector. Thus, unlike before, when the location of production capacity was determined to a large extent by national energy self-sufficiency, the motivation for establishing new production technology is now also determined by international arrangements in relation to renewable energy and emission limitations.

As a result of the study, an immediate consequence is increased pressure on transmission lines. The transmission quantities indicated in the analysis will clearly motivate or force investments in increased international transmission capacity. If this does not take place and result in a segmentation of the electricity spot market, some of the efficiency gains, which are the motivation for the introduction of TEP and TGC markets, will be lost. There are other perspectives of the restructuring of the electricity system that may result from the introduction of TEP and TGC markets. Thus, a significant increase in wind power will have to be counterbalanced by measures such as access to production technologies with fast regulating properties and/or that may maintain voltage stability. However, one consequence of the pursuit of a renewable energy goal is to reduce the spot price of electricity - therefore, the motivation for investments in traditional technologies with such desirable qualities will be lower. In other words, the price signals of TGC's (and to some extent also TEP's) that will enhance wind power investments will simultaneously hamper investments in technologies that are a precondition for extensive use of wind power technologies.

In a study by Morthorst (2003 b), the interactions of an international green certificate market and a tradable permits market in combination into a liberalised electricity market is analysed with a three-country model. The main assumptions for the model are the following:

- All three countries are all part of the same physical electricity market and there are no barriers for export/import of electricity between the countries;
- All power production from renewables is assumed to be sold at the physical electricity market, no matter what the spot market price turns out to be;
- All countries are assumed to have committed themselves to national GHG reduction targets and no emission-adjustments are allowed with regard to export/import of electricity;
- All countries have accepted the same rules for TGC trading and thus trade-in certificates flows freely across the borders and no GHG credits are attached to the green certificates;
- All countries are assumed to have accepted the same rules for TEP trading and trade-in tradable permits flows freely across the borders.

The study shows that a combination of an international tradable permits market and a green certificate market is seen to be efficient in contributing to achieving the national CO_2 reduction targets if a close co-ordination of the two instruments is undertaken at least at the national level. When power production from RE is increased, the quota of TEP should be decreased correspondingly. Otherwise, the expected CO_2 reductions will not fully contribute to achieving the national targets for greenhouse gas reductions. Thus, if it is a prerequisite that renewable power contributes to achieving national GHG reduction targets, then the combination of these two markets might be the right solution.

A main conclusion from this study is that neither the use of national renewable support schemes nor the introduction of a TGC market into a liberalised power market can be recommended, if these initiatives efficiently are expected to contribute to achieving the national CO_2 reduction targets. Thus, the most ambitious countries in implementing renewable energy technologies will only partly gain the CO_2 reduction benefits themselves while less ambitious ones also achieve the benefits of this. In the case of a TGC –market, the most ambitious countries to fulfil their TGC quotas will have to buy certificates from the less ambitious ones, although this only contributes to fulfilling a national target for renewable development, not in reaching their national CO_2 reduction targets (this problem of not gaining the full CO_2 benefit of a national implementation of renewable power is not only related to green certificate markets, but is generally in character if the country takes part in a liberalised power market).

One solution to solve this problem is to combine the TGC market with a market for TEP's. In the case of a combined green certificate system and a tradable permits market, it is necessary that the quotas of the two markets are adjusted in a co-ordinated manner: When the green power production is increased, the tradable permits quota should be decreased correspondingly. The expected CO_2 reductions will otherwise not contribute by the full value in achieving the national targets for greenhouse gas reductions. Although this requires a strong co-ordination of these policy instruments, it might show the necessary way forward if renewable power is to contribute significantly to achieving the national emission reduction targets.

6 Implications for Implementation in WILMAR

The above chapters have described TEP and TGC concepts and markets. This chapter will describe the possibilities for modelling TEP and TGC aspects in the Wilmar model.

In the Wilmar model, there are three basic timescales or time horizons for the decision-making by the actors on the market: a one-hour horizon, applicable to the regulating power market; a one-day horizon, applicable to the spot market bidding; and a one-year (or longer) horizon, applicable to the determination of use of regulated hydropower.

The first two time horizons are treated together in the so-called joint market model. This implies in particular that the decision-making related to bidding is treated as an integrated process for the two time horizons. The market clearing and the determination of prices and quantities will on the assumption that the electricity market is perfect, admit no possibility of arbitrage between the two markets. We shall also in the sequel refer to the joint market as the short-term market.

In principle, something similar could be said about the relations with the third (one-year) time horizon. However, in practice, the third time horizon is much longer than any of the two others, and for this reason, the treatment in the Wilmar modelling context differs. The longer-term aspects are treated in the so-called long-term model. The interaction between the joint market model and the long-term model will be taken care of in the Wilmar model, but as concerns model details, these will be in a less integrated manner than the interaction between the spot and the regulating markets.

Seen from the point of view of the joint market model, the long-term model requirement is that it must provide boundary conditions for the joint market model. The primary goal in this respect is to do so for hydropower. The necessity of this is that the hydropower storages permit the use of hydropower throughout the whole year, even if hydropower inflow is out of phase with the electricity consumption. This is in contrast to wind power, which is not immediately storable.

For a long-term power model with a mixture of different production technologies, this amounts to solving a stochastic optimisation problem in order to find what is traditionally called water values, i.e., the expected marginal benefit of having one MWh of electricity stored in the form of water in a reservoir.

Once the water values are calculated in a long-term model, they may be used in a short-term model to provide the required boundary conditions in order to make an optimal economic dispatch.

However, there is also a connection from the short-term model to the long-term model. The water values can only be derived from the long-term model based on the cost structure assumptions in the short-term model, because the water values must essentially be equal to the expected marginal cost in the short-term model. Furthermore, from the simulation of the shorter chronological timescales throughout the year, the accumulated use of hydropower will be found, which is used in the updating of the hydro reservoir contents.

As appears from the previous chapters, the determination of the prices of TEP and TGC must be characterised as a long-term issue. For TEP and TGC, there are, therefore, similar aspects that connect short-term and long-term aspects. This will be discussed in the following.

6.1 Short-Term Aspects - Joint Market Operation

For the benefit of the following, discussion production units may be classified into units that are capacity (power) constrained and units that are energy constrained. Let us first treat the capacity constrained units.

The decision of whether to bid a given quantity of electricity into the short-term market (spot and/or regulating – cf. the joint market concept in Wilmar) is based on a comparison between the marginal cost of production and the expected electricity price. Assuming perfect competition, the whole capacity should ideally be bid into the market; the question is only at which price.

The price to be used for bidding is the net marginal cost, i.e., the marginal cost minus any marginal income. The marginal cost will be assumed known. However, in the short-term perspective, the marginal income need not be known, at least not with certainty.

If there is only one market with which there is no difficulty. However, there may be more than one relevant market. Thus, with a TGC market, the operator of, for example, a biomass-fuelled unit faces two distinct types of markets: one for TGC and another for spot and regulating electricity (i.e., short-term markets in the above terminology). If the price in one market, e.g., the TGC price, were known, the relevant price to use for bidding on the other, the spot market, would be the marginal operation cost minus the TGC price. But the TGC price cannot be known from the operation of the short-term markets, and it will have to be introduced endogenously.

Similar considerations apply to the TEP. In order that the net marginal cost of, for example, a gas fired production unit may be known, the TEP price must be know. However, the TEP price is determined in a longer perspective, related to annual emission quotas.

Given the two prices, for TEP and for TGC, the solution of the short-term market problem, as performed in the Wilmar joint market model, will be no more complicated than in a system without TEP and TGC. The only slight complication is that a data element must be kept, which represents the TEP and the TGC price and that these have to be incorporated into the net marginal cost calculation. The result of the market clearing will be different, due to the different magnitudes with which the TEP and TGC prices affect the marginal cost on the different units.

If the fuel efficiency of a unit is constant, then the net marginal cost may be calculated as a fixed number (for given cost components). If fuel efficiency depends on the production level, then the different component in the determination of the net marginal cost will contribute in non-constant proportions. If, for example, the fuel efficiency of a gas fired unit has a maximum at 80% of full load, then increasing electricity output to 90% of full load in a given hour will increase the income from electricity sales by 12.5%. But the fuel cost will increase more, and so will the cost of acquiring TEP, which matches the increased emission.

As concerns energy constrained units, e.g., small hydro, the situation is somewhat similar. Again, the net marginal cost is a relevant issue for the determination of bidding. However, in addition, the water value must be taken into consideration, i.e., the expected value of the stored water.

Furthermore, if the efficiency is not a constant, but depends on the power output, this must be taken into consideration. For example, operating at the most efficient point may permit the production of 100 MWh of electricity from a certain amount of water, but operating at a lower efficiency may permit only 90 MWh from the same amount of water. This will imply a reduction in the sale of TGC of 10%. This loss has to be balanced against the potential increase of net income from increased sale of electricity in peak price hours and decreased sale in low price hours.

The conclusion for the implementation in the WILMAR joint market model is that the TEP market will be implemented using an endogenously given TEP price. This price can either come from the long-term model, see below, of may be assumed from consideration of, for example, world market prices for TEP.

Whether the TGC will be implemented in the WILMAR joint market model is not yet decided. As appears from the previous discussion, it seems less relevant for the short-tem operational issues. Furthermore, it will depend in part on the way the short-term energy and power issues of hydro will be modelled, since this will determine the possibilities of inclusion of TGC.

6.2 Long-Term Aspects – The Long-Term Model

The main functioning of the long-term model in relation to hydropower long-term scheduling is to provide water values on a feedback form, viz., for any particular time of the year (e.g., week number) dependent on the content of water in the reservoirs. From an abstract point of view, the TEP and the TGC may be treated in a similar way.

Assume for TEP that a closed market with annual emission quota for the electricity and CHP sector is in force. What corresponds to content of water will then for the TEP be the remaining part of the emission quota. Thus, if, for example, the remaining part for a given week is below normal (suitably defined), then the expected price of TEP will be above normal. For TGC, the amount of certificates corresponds to the content of water. Thus, if, for example, the amount for a given week is below normal (suitably defined), then the expected price of TEP will be above normal. Therefore, the general principles of inclusion of the TEP and TGC in the long-term model are clear, although obviously details differ.

One issue in the interplay between the short and the long-term models is related to the level of details. In order to obtain a solution to the long-term model, it will be necessary to sacrifice some details in order to reduce calculation time. This may be in the specification of the production units, in the number of time steps used or otherwise. As is well-known, such simplification will typically imply an underestimation of the calculated optimal cost. This in turn must be corrected in the linkage between the short and the long-term models. For the TEP and the TGC, similar effects are expected and they will have to be taken care of.

In the Wilmar model, the simple way to include the price of TEP and TGC is to estimate them outside the model and then incorporate these values on the joint market model. From the point of view of the joint market model, this will be satisfactory. Moreover, it may be argued that since the geographical extension considered in the Wilmar model is small compared to the market extensions for TEP and TGC, this is the relevant way to do it. This was the idea in the project description.

On the other hand, it may be interesting and relevant in the present project context to provide a modelling tool that can treat the situation where the considered geographical extension is large, such that climate effects like hydro inflow of wind power variation, or policy issues matter. As indicated above, the implementation may in general terms be said to follow the ideas in the long-term model's implementation of the water values, but the distinctive details are expected to require considerable attention. Whether TEP and TGC will be implemented in the long-term model will be decided later.

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